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H. B. Hale, B. O. Hartman, D. A. Harris, E. W. Williams, R. E. Miranda, J. M. Hosenfeld, and B. N. Smith

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13. ABSTRACT

By use of a battery of urinary techniques, the physiologic cost (stress) of prolonged C-141 flying operations (either staged or nearly-continuous) was shown to be mild-to moderate in degree. Staged missions lasting 5 or 7 days tended to be less stressful than double-crew nearly-continuous 50-hour missions. In the latter type of mission, two extremely different work/rest schedules, namely, 4/4 and 16/16 hours, induced similar degrees of physiologic stress. Anticipatory stress which was detected prior to double-crew flights tended to be higher than the flight stress that followed. Crew position was a contributory factor, slightly modifying flight and postflight trends. Pre-existing circadian periodicity persisted, although flight had modifying influence. Time of day that represented night at home were the times of highest sensitivity to flight. Recovery from prolonged nearly-continuous flying operations appears to require 4-5 days, and it appears to be a multiphasic process, with endocrine-metabolic depression appearing first, after which there was oscillation and final settling at the control level. In one double-crew mission, when extraordinary fatigue was noted, there had been a 12-hour pattern of change in the physiologic stress index that suggested an "overload" reaction.

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Physiologic Stress During 50-Hour Double-crew Missions in C-141 Aircraft

H. B. HALE, B. O. HARTMAN, D. A. HARRIS, E. W. WILLIAMS, R. E. MIRANDA, J. M. HOSENFELD and B. N. SMITH
USAF School of Aerospace Medicine, Brooks Air Force Base, Texas 78235

HALE, H. B., B. O. HARTMAN, D. A. HARRIS, E. W. WILLIAMS, R. E. MIRANDA, J. M. HOSENFELD and B. N. SMITH. *Physiologic stress during 50-hour double-crew missions in C-141 aircraft.* Aerospace Med. 43(3):293-299, 1972.

By use of a battery of urinary techniques, the physiologic cost (stress) of prolonged C-141 flying operations (either staged or nearly continuous) was shown to be mild-to-moderate in degree. Staged missions lasting 5 to 7 days tended to be less stressful than double-crew nearly continuous 50-hour missions. In the latter type of mission, two extremely different work/rest schedules, namely, 4/4 and 16/16 hours, induced similar degrees of physiologic stress. Anticipatory stress which was detected prior to double-crew flights tended to be higher than the flight stress that followed. Crew position was a contributory factor, slightly modifying flight and postflight trends. Pre-existing circadian periodicity persisted, although flight had modifying influence. Times of day that represented night at home were the times of highest sensitivity to flight. Recovery from prolonged, nearly continuous flying operations appears to require 4-5 days, and it appears to be a multiphasic process, with endocrine-metabolic depression appearing first, after which there was oscillation and final settling at the control level. In one double-crew mission, when extraordinary fatigue was noted, there had been a 12-hour pattern of change in the physiologic stress index that suggested an "overload" reaction.

THIS RESEARCH WAS PART of an extensive effort concerned with various physiologic and psychologic effects of prolonged flying missions in which two crews alternately operated the aircraft. An earlier report[1] presented oral temperature data for the crews. The present report presents endocrine and metabolic data. The objectives in this study were as follows: (a) to test for differential effects of two work/rest schedules (4/4 hours and 16/16 hours), (b) to quantify the anticipatory and flight-induced stress, (c) to test for relationship between flight-stress severity and flight duration, (d) to test for relationship between flight-stress severity and crew position, and (e) to ascertain whether recovery from this flight-stress was prompt or not.

This investigation was accomplished jointly by personnel in (a) the Environmental Sciences Division and the Clinical Sciences Division of the USAF School of Aerospace Medicine, Brooks AFB, Texas, (b) Headquarters, Military Airlift Command, Scott AFB, Illinois, and (c) the 3rd Military Airlift Squadron, Charleston AFB, South Carolina. The responsible medical officer for MAC was Lt. Col. J. A. Martinez. Further reproduction of this report is authorized to satisfy the needs of the United States Government. Reprints may be obtained from Henry B. Hale, Ph.D., Environmental Sciences Division (SME), USAF School of Aerospace Medicine, Brooks AFB, Texas 78235.

METHODS

Urine specimens were collected from the crew members at approximately 4-hour intervals (except when prevented by sleep) during flight and postflight periods. For the purpose of assessing anticipatory stress, the first urine collection in each mission covered the 2 hours that preceded departure and the first 2 hours of flight. This overlap into the flight period makes allowance for a lag that urinary stress indices generally show, since urinary changes tend to be about 2 hours behind the physiologic events they reflect.

The physiologic aspects under study all show circadian periodicity under ordinary circumstances; therefore, the urine collections had to be standardized with respect to time of day. To accomplish this synchronization, the different missions were all started in the period of 0800-0900 hours. The physiologic data are most meaningful when viewed in relation to the time zone to which the crew members were physiologically entrained, namely, Eastern Standard Time. The urinary stress indices were expected to show either *entrainment per se* or *entrainment plus stress.* To reveal each stress effect, the entrainment effect was to be extracted mathematically by the use of control (baseline) data obtained from unstressed persons.

The stress indices were as follows: *norepinephrine, epinephrine, 17-hydroxycorticosteroids (17-OHCS), potassium, sodium,* the *sodium/potassium ratio (Na/K),* and *urea.* Stressors have stimulatory influence on the regulatory systems of the body as well as on fundamental metabolic activities, particularly the energy-releasing (catabolic) processes. Urinary norepinephrine and epinephrine determinations[2] enabled indirect assessment of activity levels in the sympathetic nervous system and the adrenal medulla, respectively. One phase of adrenocortical activity was quantified by means of urinary 17-OHCS determinations.[3] Urinary potassium

and sodium determinations* enabled limited appraisal of mineral metabolism, and the Na/K ratio served to indicate whether or not there is a weak or strong regulation of the distribution and/or excretion of these two ions. Urinary urea,† a by-product of protein catabolism, provided rough quantification of protein breakdown rates. Urinary creatinine,† an index of lean body mass, was used as an adjusting factor, not a stress index. By expressing the individual hormones and metabolites as creatinine-based ratios, the influences of the factors of body size and age are minimized. Moreover, precise timing of urine collections is unnecessary.

RESULTS

C-141 Double-crew Missions

Three of the missions employed the short work/rest schedule (4/4 hours). Four others employed the long work/rest schedule (16/16 hours). One of the latter missions was terminated prematurely owing to overfatigue, so it will be reported separately. As the first step in the organization and analysis of the urinary data for the six successful missions, those obtained at each point in time for a given individual during the three 4/4 missions were averaged, as were those for the three successful 16/16 missions. Thus, a time-series of values for each type of mission was derived for each crew member. To test for differential effects of the work/rest schedules, the data for 8 of the crew members were used. The double-crew is considered to contain 2 aircraft commanders, 2 copilots, 2 flight engineers, and 2 navigators. Variance analyses were performed, using flight and postflight data and flight-postflight differences. Only questionable evidence of differentiation was found, which was limited to urea ($P < 0.05$) and Na/K ($P < 0.05$). We conclude, therefore, that endocrine-metabolic activity levels related primarily to factors other than the work/rest schedules. Pooling of the 4/4 and 16/16 data was then considered reasonable. The pooled data gave a single time-series of flight values (along with a single series of postflight values) for each of the 4 crew positions, and for the crew as a whole (Table I and V). The flight series in Table I contains values for each of the 13 time segments in the 50-hour flight, whereas the post-flight series has only 9 values, those for times of normal wakefulness. The urine specimens for the nocturnal (sleep) portion of each postflight day (2200 to 0600 hours) were omitted deliberately, as it was thought that sleep disruption for the purpose of collecting urine might affect recovery rates adversely. Using only the data that represent the part of the day in which wakefulness the normal physiologic state, meaningful

*Determinations made on automated flame photometer (Instrumentation Laboratory, Inc.).

†Determinations made on AutoAnalyzer.

TABLE I. SUMMARY OF RESULTS

	TIME OF DAY	STRESS INDEX						
PERIOD	(EST)	NE	E	17-OHCS	K	Na	Na/K	Urea
FLIGHT	1000	5.48	1.64	365	[illegible]	16.97	3.43	1585
	1400	6.10	1.41	354	[illegible]	15.14	4.04	1616
	1800	4.64	1.20	288	[illegible]	14.29	4.66	[illegible]
	2200	3.93	0.96	218	2.06	12.10	6.33	1327
	0200	3.46	0.81	165	2.27	10.38	5.42	1275
	0600	4.34	1.16	213	2.24	9.41	5.01	1319
	1000	4.72	0.97	341	[illegible]	12.82	3.92	[illegible]
	1400	5.37	1.09	387	4.26	13.29	3.47	1417
	1800	4.92	1.31	374	4.24	13.66	3.73	1410
	2200	3.65	0.73	280	2.66	11.40	4.61	1218
	0200	3.67	0.85	199	2.64	9.97	4.49	1249
	0600	4.98	1.15	268	2.80	10.10	4.31	1357
	1000	5.47	1.09	371	4.80	12.49	2.81	1454
	(mean)	(4.92)	(1.16)	([illegible])	(3.86)	(13.46)	(4.11)	(1442)
POSTFLIGHT	1000	2.92	0.66	268	4.48	6.73	1.55	963
	1400	3.20	0.84	258	4.83	8.72	1.95	1044
	1800	3.42	0.68	200	3.90	8.20	2.30	1082
	2200	3.29	0.73	168	3.30	8.46	3.37	1129
	1000	3.83	0.76	213	4.84	8.94	2.09	1209
	1400	3.32	0.73	266	4.81	9.63	2.24	1185
	1800	3.52	0.69	214	4.08	10.04	2.88	1222
	2200	3.97	0.84	163	2.66	8.95	4.25	1256
	1000	3.07	0.67	175	3.99	7.90	2.28	1120
	(mean)	(3.39)	(0.73)	(214)	(4.10)	(8.62)	(2.55)	(1134)

Each value represents 8 crewmembers and 6 missions. Norepinephrine (NE), epinephrine (E), and Porter-Silber chromogens (17-OHCS) are all expressed as μg/100 mg creatinine. Potassium (K) and sodium (Na) are expressed as mEq/100 mg creatinine. Urea is expressed as mg/100 mg creatinine. Within the flight period, relationship to time of day was detected for NE ($P < .005$), 17-OHCS ($P < .001$), K ($P < .001$), Na ($P < .01$), Na/K ($P < .001$), and urea ($P < .001$). In the postflight period, time trends were established for 17-OHCS ($P < .05$), K ($P < .025$), and Na/K ($P < .005$). Differences in time trends in flight and postflight trends were detected for 17-OHCS ($P < .05$), potassium ($P < .025$), Na/K ($P < .001$), and urea ($P < .001$). Based on overall means for flight-postflight differences, significant variation was found for NE ($P < .005$), E ($P < .025$), 17-OHCS ($P < .005$), Na/K ($P < .005$), and urea ($P < .005$), but not for K. The "flight means" and the "postflight means" in this table were derived from 1000-2200 values.

flight-postflight variation was detected for all of the physiologic variables. Most of the flight values (means for the 9 selected times in the flight period), when expressed as percent deviation from the respective postflight values, tended to clump around one level. Specifically, the epinephrine and 17-OHCS deviations were +59 and +55, respectively; the sodium and Na/K deviations amounted to +56 and +61, respectively; the norepinephrine deviation was +45; and the urea deviation was +27.

To provide perspective, data are presented in Table II for a control group containing 10 flyers, each of whom collected 4-hour urine specimens during a day of ground duty that was not preceded by a day of flying duty. The mean values presented in this table for the control and experimental groups each represent the 16-hour period (0600 to 2200 hours, Eastern Standard Time) in which wakefulness is the usual physiologic state. The difference between each flight (or postflight) value and the corresponding control value has been expressed as percent deviation from that control value. This treatment not only extracts the entrainment effect, but it also places the 7 stress indices on a common scale. Distinct gradation in responsiveness is evident for the various indices. The sodium response consistently outranked all others, and the 17-OHCS response consistently remained at the bottom of the list. Except for 17-OHCS, all of the indices show higher responsiveness on the first day of flight than on the second day, perhaps because of anticipatory stress (see later comment). The 17-OHCS pattern of change during the flight period suggests adrenocortical unresponsiveness to flight factors on the first day, with low-grade responsiveness developing subsequently. Flight duration evidently acted as a potentiating factor in this particular case. By summating algebraically and then averaging the deviations for the 7 different indices, an overall endocrine-metabolic index was derived, which enables characterization of and comparison of early and late tendencies in the flight and postflight periods. On this basis, the first flight day appears to have been the more stressful of the two, and near-stability (at virtually the baseline level) is indicated during the 2-day postflight period. Recovery from this long-duration flying operation evidently involved sympathoadrenomedullary and adrenocortical depression, for there was sustained negative deviation for epinephrine, norepinephrine, and 17-OHCS during the postflight period. The remaining indices, with the excep-

TABLE II. FLIGHT-POSTFLIGHT VARIATION
(Data for Period of Wakefulness)

STRESS INDEX	CONTROL GROUP (n = 10)	FLYING GROUP (n = 8) FLIGHT DAY 1	FLIGHT DAY 2	POSTFLIGHT DAY 1	POSTFLIGHT DAY 2
Sodium, mEq	7.45	14.62 (+96%)	12.54 (+68%)	8.03 (+ 8%)	9.39 (+26%)
Epinephrine, μg	0.81	1.30 (+60%)	1.02 (+26%)	0.73 (−10%)	0.76 (− 6%)
Na/K	2.98	4.62 (+55%)	3.93 (+32%)	2.29 (−23%)	2.86 (− 4%)
Urea, mg	1092	1534 (+40%)	1347 (+23%)	1054 (− 3%)	1218 (+12%)
Norepinephrine, μg	3.78	5.04 (+33%)	4.67 (+24%)	3.21 (−15%)	3.66 (− 3%)
Potassium, mEq	2.95	3.81 (+29%)	3.67 (+24%)	4.13 (+40%)	4.10 (+39%)
17-OHCS, μg	293	306 (+ 4%)	346 (+18%)	224 (−24%)	214 (−27%)
(Mean Deviation)	–	(+45%)	(+31%)	(− 4%)	(+ 5%)

Each value is the mean for the 16-hour period in which wakefulness is the normal state (0600 to 2200 hours EST). Except for Na/K, each value is a creatinine-based ratio (amount/100 mg creatinine). The % deviation from the corresponding control value is shown in parentheses below each experimental value.

TABLE III. FLIGHT VARIATION
(Data for Nocturnal Period)

STRESS INDEX	CONTROL GROUPS NONFLYER (n = 12)	FLYER (n = 10)	FLYING GROUP (n = 8) FLIGHT NIGHT 1	FLIGHT NIGHT 2
Epinephrine, μg	0.45	0.56	0.98 (+75%)	1.00 (+ 79%)
17-OHCS, μg	107	116	189 (+63%)	234 (+102%)
Sodium, mEq	7.43	6.18	9.90 (+60%)	10.04 (+ 62%)
Norepinephrine, μg	2.13	2.56	3.90 (+52%)	4.32 (+ 69%)
Na/K	4.16	3.60	5.23 (+45%)	4.40 (+ 22%)
Potassium, mEq	1.95	1.82	2.26 (+24%)	2.72 (+ 50%)
Urea, mg	1077	1108	1297 (+17%)	1303 (+ 18%)
(Mean Deviation)	–	–	– (+48%)	– (+ 57%)

Each value represents the 8-hour period normally given to sleep (2200 to 0600 hours EST). Both of the control groups slept during this period. Except for Na/K, each value is a creatinine-based ratio (amount/100 mg creatinine). The % deviation from the corresponding flyer control value is shown in parentheses beside each experimental value.

tion of potassium, tended to approach their respective baselines during the postflight period, thereby indicating that most of the flight effects were readily reversed. Potassium, however, showed a sustained increase over the levels found in the flight period, apparently denoting residual or secondary nonspecific stress.

Table III presents the deviations from baselines found for the individual (and the overall) stress indices during the nocturnal portion of each flight day (Eastern Standard Time). The 10 flyers who provided control data for the earlier portion of the day (the period of wakefulness) also provided the nocturnal control data, breaking their sleep on the test night at the end of 4 hours and again at the end of 8 hours. Their urine collection schedule was, therefore, the same as that used by the C-141 double-crew during flight. The second set of nocturnal control values in Table III represents 12 members of the laboratory staff, each of whom collected one overnight urine specimen per week during the 13 weeks of spring, the season in which the C-141 test flights were flown. These control specimens, however, are representative of unbroken sleep periods. Despite the differences in collection schedules, the two sets of control data show close agreement in all respects. We conclude, therefore, that they both represent a stress-free state. Variances are not considered, since the flyers who made up the control group were studied on a single test night, whereas the nonflyers were studied repeatedly.

Stress severity during the nocturnal period, as judged by 17-OHCS output, was greater than that in the period of wakefulness (so-called "daytime"). The 17-OHCS response to flight on the first night was next to the highest of the 7 indices, and it increased as flight duration increased. Thus, there is basic agreement between the nighttime and daytime adrenocortical responses in that each indicated that flight duration was a positive, contributory factor. The relatively high 17-OHCS responsiveness evident in the nocturnal period probably relates in part to the added factor of sleep deprivation. Norepinephrine also suggests higher responsiveness during the nocturnal period than during the wakefulness period; and like 17-OHCS, norepinephrine showed intensification in nocturnal responsiveness as flight duration increased. Epinephrine responsiveness at night was consistently above that for the earlier part of the day, but it did not show relationship to flight duration, nor did it follow its own daytime pattern. Potas-

TABLE IV. ANTICIPATORY-STRESS VS FLIGHT-STRESS

STRESS INDEX	BASELINE VALUES	FLIGHT VALUES INITIAL	MIDDLE	FINAL	POSTFLIGHT VALUES
Norepinephrine, µg	3.72	+ 47	+27	+47	−27
Epinephrine, µg	0.71	+131	+37	+54	− 7
17-OHCS, µg	360	+ 1	− 5	+ 3	−26
Potassium, mEq	3.52	+ 53	0	+36	+27
Sodium, mEq	7.23	+135	+63	+73	− 7
Na/K	2.18	+ 57	+80	+29	−29
Urea, mg	1170	+ 35	+15	+24	−18
(Mean Deviation)	–	+ 66	+31	+38	−12

Each value represents the 4-hour period from 0600 to 1000 hours (EST). Each flight (and postflight) value has been expressed as percent deviation from the respective baseline value. Control values are creatinine-based and represent 10 other flyers on a day of ground duty.

TABLE V. STRESS-SEVERITY IN RELATION TO CREW POSITION

STRESS INDEX	PERIOD	CREW POSITION AC	FE	CP	NAV	CREW MEAN
Sodium/Creatinine (mEq/100 mg)	Flight	13.53 (+82)	14.42 (+94)	13.05 (+75)	12.86 (+73)	13.46 (+81)
	Postflight	9.17 (+23)	9.70 (+30)	7.53 (+ 1)	8.08 (+ 8)	8.62 (+16)
Epinephrine/Creatinine (µg/100 mg)	Flight	1.34 (+65)	1.03 (+27)	1.14 (+41)	1.11 (+37)	1.16 (+43)
	Postflight	0.87 (+ 7)	0.77 (− 5)	0.63 (−22)	0.66 (−19)	0.73 (−10)
Na/K (mEq/mEq)	Flight	3.39 (+14)	4.64 (+56)	4.67 (+57)	3.84 (+29)	4.11 (+38)
	Postflight	2.40 (−19)	2.88 (− 3)	2.61 (−12)	2.30 (−23)	2.55 (−14)
Urea/Creatinine (mg/100 mg)	Flight	1405 (+29)	1527 (+40)	1397 (+28)	1439 (+32)	1442 (+32)
	Postflight	1135 (+ 4)	1240 (+14)	1012 (− 8)	1151 (+ 5)	1134 (+ 4)
Potassium/Creatinine (mEq/100 mg)	Flight	4.68 (+59)	3.50 (+19)	3.31 (+13)	3.92 (+33)	3.86 (+31)
	Postflight	4.25 (+44)	4.10 (+39)	3.50 (+10)	4.55 (+54)	4.10 (+39)
Norepinephrine/Creatinine (mEq/100 mg)	Flight	5.98 (+58)	4.69 (+24)	4.29 (+13)	4.73 (+25)	4.92 (+30)
	Postflight	4.00 (+ 6)	3.59 (− 5)	3.06 (−19)	2.89 (−24)	3.39 (−10)
17-OHCS/Creatinine (µg/100 mg)	Flight	367 (+25)	314 (+ 7)	347 (+18)	295 (+ 1)	331 (+13)
	Postflight	224 (−24)	231 (−21)	205 (−30)	181 (−38)	214 (−27)
(Mean Deviation)	Flight	– (+47)	– (+38)	– (+35)	– (+33)	– (+38)
	Postflight	– (+ 6)	– (+ 7)	– (−10)	– (− 5)	– (0)

Values for the individual crew positions each represent 2 crewmembers, 6 missions, and 9 "daytime" determinations per crewmember. Each period lasted 50 hours, and the physiologic determinations were all made during the period of wakefulness (0600-2200 hours, EST). Values in parentheses indicate % deviation from a baseline value (see text).

sium deviation on the first night approximated the level found during the first daytime period, but that for the second night was high relative to its daytime value. Sodium deviation on the first night was low compared to its daytime value; but on the second night, it approximated the corresponding daytime value. The nocturnal area responses were consistently low relative to daytime values. The Na/K ratios at night followed the pattern of change seen in daytime periods, namely, a decline in responsiveness with time. The nocturnal Na/K deviations were both slightly lower in magnitude than the corresponding day deviations. Collectively, the 7 stress indices (see mean deviation) indicate progressive stress-intensity in nocturnal flying. This pattern of variation is opposite to that for daytime flight.

For the purpose of characterizing the anticipatory stress, each of the values obtained at the initial flight time (1000 hours) was expressed as percent deviation from a baseline (control) value. The derived values appear in Table IV, along with values obtained at 1000 hours on the second and third flight days and on the first postflight day. The initial flight values were expected to reflect mainly the psychogenic stress developed in the preflight period, since urinary indices have an inherent lag. The middle and final flight values serve to characterize the flight-induced stress, and perspective is gained by the use of the postflight data. The mean deviations vary in a way that suggests that the anticipatory stress level was about 2 times greater than the flight stress levels. A relatively steady state is evident during the flight period, for the middle and final flight values tend to agree. Sympathoadrenomedullary hyperactivity (see norepinephrine and epinephrine) was a prominent feature of the anticipatory stress as well as the flight stress, but there was never evidence of accompanying adrenocortical hyperactivity.

To test for possible differences for crew positions, the serial data presented in Table I were reorganized. The 9 "daytime" flight values for a given stress index were averaged, as were the 9 corresponding postflight values (Table V). Epinephrine differentiated crew positions ($P < 0.05$). The flight data give suggestive evidence indicating that the aircraft commanders collectively experienced slightly more severe stress than the others, and the others were nearly matched in this respect. The postflight data suggest low-grade residual stress for the aircraft commanders and flight engineers, while the others show evidence of mild physiologic depression.

To study the after-effects of such long-duration flying operations, on one occasion the postflight period was extended to 5 days, during which time the members of the double-crew collected daytime urine specimens at 4-hour intervals. The mean deviations in Table VI show variation that seems meaningful. First, they provide evidence of a steady state during the flight period. Subsequently, an oscillatory trend is evident, which suggests that recovery from long-duration flying operations involves temporary endocrine-metabolic depression, fol-

TABLE VI. RECOVERY FROM FLIGHT STRESS

STRESS INDEX	FLIGHT DAYS 1	FLIGHT DAYS 2	POSTFLIGHT DAYS 1	POSTFLIGHT DAYS 2	POSTFLIGHT DAYS 3	POSTFLIGHT DAYS 4	POSTFLIGHT DAYS 5
Epinephrine	+65	− 1	−27	−26	+ 32	+14	−26
Sodium	+61	+77	0	+48	+101	+87	+37
Urea	+33	+20	−18	+17	+ 18	+21	+ 4
Potassium	+29	+38	+61	+52	+ 45	+57	+68
Norepinephrine	+28	+43	−33	−20	+ 28	+ 2	−21
Na/K	+19	+18	−42	+ 9	+ 58	+15	−24
17-OHCS	+14	+35	−26	−25	− 39	−23	−32
(Mean Deviation)	+36	+33	−12	+12	+ 35	+25	+ 1

Each value represents the 16-hour period from 0600 to 2200 hours (EST) and is expressed as percent deviation from a baseline value. The baseline value appears in Table II.

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TABLE VII. STRESS RESPONSE OF OVER-FATIGUED FLYERS

STRESS INDEX	FLIGHT	ELAPSED TIME (HOURS) 26	30	34	34-HOUR MEAN
Norepinephrine	Successful	− 45	+ 27	+29	+ 21
	Over-fatiguing	+ 99	+114	+ 8	+ 63
Epinephrine	Successful	− 52	+ 16	+31	+ 46
	Over-fatiguing	+158	+ 81	+ 2	+ 87
17-OHCS	Successful	− 7	− 13	+73	+ 30
	Over-fatiguing	+ 8	− 2	+52	+ 41
Potassium	Successful	− 1	+ 1	+32	+ 11
	Over-fatiguing	+ 34	+ 35	+21	+ 52
Sodium	Successful	+ 87	+ 25	+92	+ 61
	Over-fatiguing	+148	+ 40	+64	+102
Na/K	Successful	+ 78	+ 33	+32	+ 41
	Over-fatiguing	+ 76	+ 2	+18	+ 27
Urea	Successful	− 7	+ 16	+22	+ 19
	Over-fatiguing	+ 23	+ 42	+23	+ 35
(Mean Deviation)	Successful	+ 8	+ 15	+44	+ 33
	Over-fatiguing	+ 78	+ 45	+27	+ 58

Each value is expressed as percent deviation from a baseline value.

lowed by a period of what appears to be nonspecific stress, with reversion to the baseline finally. Thus, there is evidence indicating that full recovery required 5 days.

Evidence of over-fatigue in certain crew members was noted in one of the test flights, and the mission was terminated (aborted) at the 34th hour. A "make-up" flight was flown on a much later occasion. Since the two flights were the same with respect to itinerary and to work/rest schedule, and since the crew that suffered the unusual fatigue also flew the make-up flight, comparison of the two sets of physiologic data was feasible. For convenience, all values obtained for a given physiologic index in the 34-hour over-fatiguing flight were averaged, as were the corresponding values in the later, successful flight. These values appear in Table VII. With the exception of Na/K, each of the stress indices indicate more intense stress in the over-fatiguing flight than in the successful flight. This table also presents values for collection periods late in the overfatiguing flight (along with the corresponding values for the successful flight) for the purpose of bringing out the character of the endocrine-metabolic trend during the 12-hour period in which the fatigue in the unsuccessful flight must have been developing. The three mean deviations in the successful flight increased progressively, whereas those in the over-fatiguing flight declined progressively. The high initial value and the decline exhibited by the over-fatigued group suggests an "overload" reaction.

TABLE VIII. STRESS TRENDS DURING 5-DAY STAGED MISSION

STRESS INDEX	STAGE 1	2	3	4
Norepinephrine	+ 6	+56	+142	+ 11
Epinephrine	+41	+ 8	+193	+ 30
17-OHCS	+12	+22	+218	+ 99
Potassium	+ 7	− 2	+ 70	+133
Sodium	+16	+50	+139	+ 99
Na/K	+ 8	+37	+ 40	− 26
Urea	+20	+ 7	+ 49	+ 20
(Mean Deviation)	+17	+25	+122	+ 51

Each value is expressed as percent deviation from a control value.

TABLE IX. STRESS TRENDS DURING 7-DAY STAGED MISSION

STRESS INDEX	STAGE 1	2	3	4	5	6
Norepinephrine	+24	+ 14	+ 64	−49	+60	− 1
Epinephrine	0	+108	+ 99	−39	+56	− 9
17-OHCS	−37	− 55	− 52	−52	−59	−50
Potassium	+ 7	− 14	+114	+14	− 3	+18
Sodium	+82	+ 61	+ 84	−19	+25	+28
Na/K	+85	+ 91	− 8	− 7	+41	+ 4
Urea	+ 9	+ 11	+ 13	+ 9	+16	+11
(Mean Deviation)	+24	+ 31	+ 45	−13	+19	0

C-141 Single-crew Staged Missions

Physiologic data were collected for other C-141 crew members during a 5-day staged mission of the type that is typical for MAC. On the first day, urine specimens were collected during flight for each of the 5 crew members at times of day corresponding to 2000, 2400, 0400, and 0800 hours (EST). The collection times during flight on the second day corresponded to 0300, 0700, and 1100 hours (EST). There was no flying on the third day. On the fourth day the collection times during flight corresponded to 2400 and 0400 hours (EST), while those for the final day corresponded to 2200 and 0200 hours (EST). As a simplifying procedure daily means were computed for each physiologic variable. Control values (which were obtained from other men at corresponding times of day) were also averaged to give daily values. Next, each mean test value was expressed as percent deviation from the corresponding control mean. As shown in Table VIII, the deviations (individually or collectively) provide evidence of stress of widely different degree on the different days. The mean deviations suggest that the stress was mildest on the first day and most intense on the fourth day (a day spent in or near a combat zone in Vietnam). The grade of stress on the final day was less than maximal, but not as low as that on the second day. Since the different daily values in Table VIII were derived from unequal sets of data, the day-to-day trends are, of course, subject to question. As a means of offset-

TABLE X. SINGLE CREW VS DOUBLE CREW

STRESS INDEX	CREW	TIME OF DAY 2000-2200	2400-0200	0400-0600	0800-1000	16-HOUR MEAN
Norepinephrine	Single	−28	+29	+ 18	10	+10
	Double	− 3	+24	+101	+ 10	+33
Epinephrine	Single	−10	+44	+ 11	+138	+46
	Double	+ 3	+46	+149	0	+50
17-OHCS	Single	+ 9	+52	+ 37	− 6	+13
	Double	− 3	+49	+ 74	− 5	+29
Potassium	Single	+69	+28	+ 9	− 38	+10
	Double	− 3	+22	− 5	− 3	+ 3
Sodium	Single	+ 6	+ 1	+ 67	− 3	+10
	Double	+87	+52	+ 62	+ 63	+66
Na/K	Single	−37	+ 2	+ 41	+ 44	+12
	Double	+77	+46	+ 87	+ 80	+68
Urea	Single	+21	+14	+ 24	+ 19	+20
	Double	+28	+14	+ 21	+ 15	+20
(Mean Deviation)	Single	(+ 4)	(+24)	(+ 30)	(+ 25)	(+17)
	Double	(+27)	(+30)	(+ 67)	(+ 23)	(+38)

Each value is expressed as percent deviation from a control value. Values for the single crew represent 5 men studied on one mission; those for the double crew represent 8 men studied on three missions (work/rest schedules = 16/16 hours).

ting criticism, comparisons were made of flight data that were obtained at similar times of day on the different days. For the time period of 0200-0400 hours (EST), there were data for Mission Days 1, 2, 4, and 5, and the mean deviations were +30%, +34%, +77% and 93% respectively. For the slightly earlier time period of 2200-2400 hours (EST), there were data for only 3 of the flight days (Days 1, 4, and 5). The mean deviations for these days were +24%, +138%, and +18%, respectively. Certain of the values for the individual indices at 2200-2400 hour (EST) in Day 4 were extremely high (norepinephrine, +187%; epinephrine, +305%; 17-OHCS, +135%; potassium, +119%, and sodium, +146%).

Data obtained during a 7-day staged mission appear in Table IX. The times of day at which the urines were collected varied with days, and there were times when some of the crewmembers lacked data. Most of the data represent the period of 0300-1300 hours (EST). Following the procedure used for the 5-day mission, a mean value was derived for each day of flight, and each daily value was expressed as percent deviation from its control. Only low-grade stress is indicated by these data. In addition to the comparisons made in Table IX, we also considered the day-to-day differences for one specific period, namely, 1000-13000 hours (EST). Data representing this period were available on Days 2, 3, 5, and 7. The mean deviations were +29%, +45%, and +39%, and −9%, respectively.

Table X compares results in single- and double-crew C-141 flights. In both flights, the grades of stress (as measured by the mean deviations) varied with time of day, tending to increase progressively during the nocturnal period, reaching a peak in the period of 0400-0600 hours (EST), and declining in the early forenoon. Despite the common pattern of change, the single and double crews appear to have incurred different grades of stress, for the mean deviation for the 16-hour test period for the double crew was approximately 2 times greater than that for the single crew. The latter crew, of course, had on-ground sleep periods, whereas the double-crew did not.

DISCUSSION

The data reduction accomplished in this study was for the purpose of obliterating to the maximum extent the "scatter" that is inherent in "field" studies. The pooling of the data for the six successful missions was advantageous, bringing out the circadian periodicity clearly. The circadian variability in responsiveness to flight factors will be elaborated upon in an additional report. Baseline studies on the members of the double-crew, while highly desirable, were impractical, so ground-based data for another group of flyers was substituted. The flight-postflight differences found by use of the pooled data proved to be meaningful both statistically and physiologically, hence it seemed proper to test for flight-induced modifications of circadian shifts. Physiologists have long used "percent deviation" from a baseline (control) level for the purpose of crudely quantifying specific physiologic responses to adverse factors acting singly or in combination. Some distortion may result from conversion to percentage, so for ordinary purposes it is better to express the deviations in absolute terms. For the present purpose, the use of percentage was merely expedient, enabling us to combine the results for a number of interrelated physiologic functions. Flight surgeons are thus provided with a single measure of stress. The "mean deviation" for the component stress responses is not necessarily a precise measure of the aggregate physiologic response. The subordinate responses appear to be weighted differentially when expressed in percentage terms, so the derived value for the group of responses may be reasonably correct or even be a somewhat conservative measure. Currently, investigators tend to use single stress measures (for example, urinary epinephrine), but this may over-estimate the stress, for this is a low-threshold response. In the present effort, for example, epinephrine responses were at times not accompanied by 17-OHCS responses, which means that the stressor had not triggered an important high-threshold response.

Of importance was the finding that urinary sodium was a very sensitive stress indicator. Sodium determinations are very simple and rapid, while hormone determinations are complicated and quite time-consuming. Flight surgeons who might wish to screen for physiologic stress in large-scale flying operations would find urinary sodium (and potassium) determinations very advantageous. Potassium was especially useful, since it detected residual flight stress.

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